A SIMULATION STUDY ON MODEL PREDICTIVE CONTROL APPLICATION FOR DEPROPANIZER USING ASPEN HYSYS

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ABSTRACT

A model predictive control strategy was proposed for control problem in a distillation column. The aim was to demonstrate process models of depropanizer from step test data and to design an advanced process control (APC) scheme to replace conventional controller for distillation column. The simulation study was conducted using ASPEN HYSYS. In order to achieve the objectives, data was collected from process of depropanizer that used proportional integral derivative controller (PID) controller and the step test was run. Model predictive control (MPC) action was calculated using system identification techniques in MATLAB and process model was obtained. MPC was applied and performance of PID and MPC was compared using set point tracking.The results confirmed the potentials of the proposed strategy. Process model 2x2 constrained MPC was develop in this study. Based on the comparison of the two control methods, results presented prove that MPC can replace conventional controller, PID controller for a distillation column control. MPC also shows greater performances than PID in terms of set point tracking. Hence, MPC controller offers better control performances than PID controller, especially in multivariable processes.

SATU KAJIAN SIMULASI MENGAPLIKASIKAN MODEL KAWALAN RAMALAN UNTUK DEPROPANIZER MENGGUNAKAN ASPEN HYSYS

ABSTRAK

Satu strategi mengawal ramalan model telah dicadangkan untuk masalah kawalan dalam turus penyulingan Tujuan projek ini ialah untuk menghasilkan model proses penyahpropana dari data ujian berperingkat dan merangka satu kawalan proses maju (APC) untuk menggantikan kawalan konvensional untuk turus penyulingan. Kajian simulasi telah dijalankan menggunakan ASPEN HYSYS. Bagi mencapai objektif, data diperolehi daripada proses penyahpropana yang menggunakan kawalan hasil bezaan penting berkadar (PID) dan ujian berperingkat dijalankan. Model kawalan ramalan (MPC) tindakan dikira menggunakan teknik pengenalpastian system dalam MATLAB dan model proses telah diperolehi. MPC telah diaplikasi dan prestasi PID and MPC dibandingkan menggunakan keputusan titik set .Keputusan yang diperolehi mengesahkan potensi strategi yang dicadangkan. Model proses 2x2 MPC dapat dihasilkan dalam kajian ini. Berdasarkan perbandingan dua kaedah pengawalan, keputusan membuktikan bahawa MPC boleh menggantikan kawalan konvensional, PID untuk kawalan turus penyulingan. MPC juga menunjukkan prestasi lebih bagus daripada PID dalam soal penjejakan titik set. Oleh itu, kawalan MPC menunjukkan respon kawalan yang lebih baik daripada PID,terutama sekali dalam proses yang mempunyai pelbagai pembolehubah.

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$\hat{y}(t / t)$	Output value estimated by the model.
$\hat{x}(t + j / t)$	The disturbance at instant t along the horizon.
$r(t + j)$	Future set point
$w(t + j)$	First order approach to the known reference
FOPDT	First order plus time delay
MIMO	Multiple-input multiple-output
MPC	Model predictive control
OP1	Operating parameter 1
OP2	Operating parameter 2
PID	Proportional integral derivative
PV1	Process variable 1
PV2	Process variable 2
SISO	Single-input single-output
SP1	Set point 1
SP2	Set point 2

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Malaysia has a dynamic and important industry. Since 1980s, the economy of Malaysia has transformed from a product-based to a producing-based economy. Furthermore, the industry in Malaysia has expanded cause by miscellaneous factor by the industry including the availability of feedstock, good infrastructure and strategic location in Asian. There are many industries in Malaysia and chemical industry is one of the dominant industries in Malaysia among rubber, food processing, and electronics.

Recently, chemical industry in Malaysia has become one of the most established chemical industries of the world (Chemical Industries Council of Malaysia). As chemicals are the main elements of other industries, chemical plant turns to be an important sector that attributes to the high demand from the manufacturing industry. The need for chemical is increasing as it produces substance that will be used in other industries.

The existence of many chemical companies namely Shell, PETRONAS, MMC Oil & Gas and ExxonMobil shows this industry has been rapidly growth in Malaysia. Chemical industry has many subsectors such as petrochemical, pharmaceutical, oleo chemical and industrial gases. Each of these subsectors is a vital towards the county's economy growth every year. In 2005, foreign investments approved in new projects amounted to RM 4.7 billion, compared with RM 9.1 billion in 2004 (Chemical Industries Council of Malaysia).

As chemical industry is very progressive recently, many factories have to compete with each other in order to attract investment from other country. Nowadays, this industry has a very strong connection to almost every other sector in Malaysia. Thus, it lead Malaysia to become one of the main export oil that contributed 6 per cent from total exports of Malaysia and 8 percent to total exports of manufactured things in January to December 2009 (Malaysia External Trade Development Corporation, 2011).

Basically, chemical industry is a large industry which involves processing and inventing desired chemicals using evaporation, absorption, separation and reaction process. During the operation, lots of equipment such as reactor, distillation column, and heat exchanger are use to get the product. Out of these equipments, distillation column is the most important in wide range of industries namely petroleum refining and chemical industries.

Distillation column is an important processing unit for separation of multi component mixtures in and purification where the productions of the final products are depends on the operation efficiency of the distillation column (Kister, 1990). According to Liptak in 2006, distillation is the most common unit operations used in separation process. In 2006, Enagandula and Riggs stated that 95 % of the separation processes for the chemical industries is using distillation column.

Basically, the physical principle of separation in distillation is the volatility difference of the components. It separates the components of a mixture based on their boiling points and the difference in the compositions of the liquids and their vapors. The purity of the product depends by the manipulation of the material and energy balance.

Due to the development of separation process, many suppliers compete with each other to produce product that has higher purity. However, the variations in feed flow rate, feed composition, utility conditions, product purity specifications and environmental changes the purity of the product.

The performance of the control system in the distillation control is important as the controller action will affect the distillate product. Controlling the distillation column will provide a better product quality and reduce waste thus increase the profitability.Therefore, a good control system must be applied to get high purity of distillation column and to have a high quality of product.

1.2 Problem Statement

Distillation column is a highly complex and requires a lot of tuning in control when variables change at different rates. Controlling the composition and purity of the product in the distillation column is one of the challenges engineers face during the operation. The steady-state operation of the column is disturbed by the sudden change in the feed flow, composition of the feed, feed pressure, and ambient temperature.

Choosing the proper control technique for distillation columns and implementing it properly is very crucial due to the effect of controller on product quality and production rate of distillation column. Besides, the control of purity of the product has a large influence on the economics of the entire process. Nowadays, as the production rate increases, the demand for separated products is also high which causes more funds to be supplied. Therefore, in order to minimize the operating cost, the products are controlled at purities.

For example, oil is one type of products from the distillation column. Oil can be divided into various types such as vegetable oils, petrochemical oils, and synthetic oils. As shown in Figure 1.1, it is predicted that in 2015 the oil consumption will increase gradually as well as the oil production even though in between 2007 and 2008, there will be rapidly decrease of oil production and consumption. The graph also shows that the price will increase by years. Hence, distillation needs to be operated in optimal conditions in order to get the desired product.

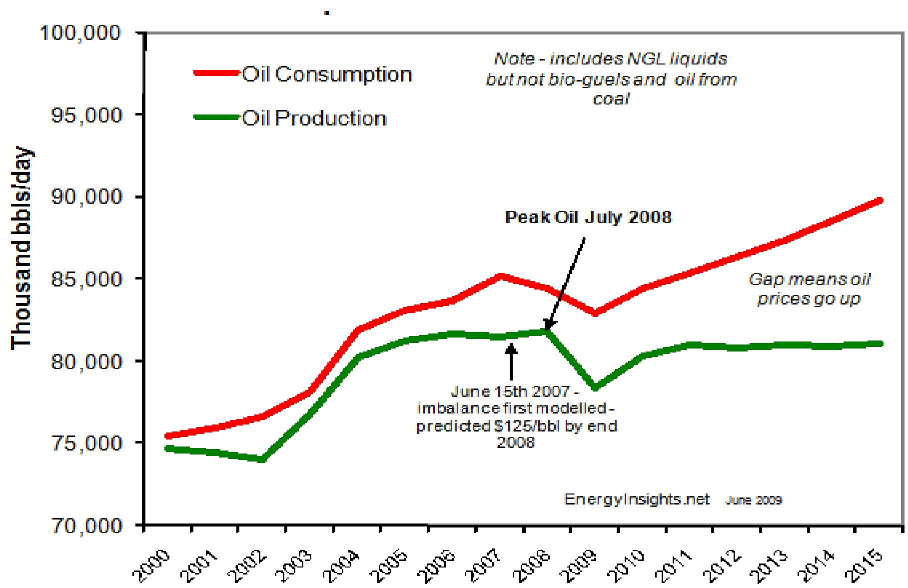

Figure 1.1 World oil consumption and production forecast (Source: Energy Insights.net, 2008).

As Malaysia is marching into the era of Science and technology, the importance of distillation is also increase. Furthermore, oil need to be distilled and new oil refineries will need to be built.Thus, the chemical process industries need a better way to optimize production of product and reduce capital costs during design a distillation column. But to control the columns to get the best products of constant composition is a very challenging because of process nonlinearity, multivariable coupling, severe disturbances and nonstationary behaviour (Riggs, 2006)

Over the past century, the Proportional Integral Derivative (PID) control has been used due to its simplicity design and its performance characteristics (Araki, 2002).Somehow, the use of PID does not meet all the needs when the processes have complex dynamics such as nonlinear and multivariable. Thus, the process cannot be optimized. To overcome this problem, advanced process control (APC) is applied.

Nowadays, APC has been added to the conventional controller. In this study, Model predictive control (MPC) is used. MPC is one types of the APC that is often used in addition to PID in large plant. MPC operates to manipulate the variables and control the input to overcome optimization problem in process control. One of the methods to illustrate MPC abilities is by controlling the distillation column. Hence, a depropanizer column has been chosen for this project.

1.3 Research Objectives

The objectives of this study are:

1.3.1. To develop process models from step test data.

1.3.2. To design an APC scheme to replace conventional controller for distillation column.

1.4 Scope of Study

In order to achieve the objectives, a simulation study on model predictive control application on depropanizer using ASPEN HYSYS was conducted. This study involves two parts that are the experiment as well as the analysis. For the experiment in case of simulation, the operation of depropanizer was simulated. Then, step test process was done to have the model of the process using Ident in MATLAB software. Later, MPC was applied. Comparison was done in terms of set point tracking and the performance of MPC was observed in order to replace the traditional controller.

1.5 Significance of Study

The MPC is offering better control responses than conventional PID controllers for distillation column to be used in industry. MPC also develops the new classes of controlling the process. In aspect of safety and environment, MPC has physical constraints like actuator limit and safety constraints like temperature and pressure limits that will limit the field of action.

1.6 Expected Outcome

The expected outcomes from this study are the control performance of depropanizer column will improve and the process model that will be obtained from step test will be used for MPC design. Then, MPC as one of the APC will be designated to overcome the problem PID faced on controlling the distillation column as the MPC is capable to operate without long periods of intervention.

1.7 Concluding Remarks

Chapter 2 is analysing about the theoretical of the research and the previous study whereas chapter 3 is discussing on the methodology of the research and how the simulation was conducted. Chapter 4 is presenting the results obtained from the simulation in HYSYS. Chapter 5 is reviewing the conclusion of this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Distillation Process

Distillation is a crucial and most common separation unit operation in chemical engineering. Distillation is illustrated as a process that removes of heat to separate a liquid or vapour mixture of two or more elements into its component fractions of desired purity (Tham, 2009).The purpose of a distillation column is to separate a mixture of substances into two or more products of different compositions.

Distillation is based on the principle of separation in distillation is the difference in the volatility of the components. Basically, the vapour of a boiling mixture will be richer in the components that have lower boiling points. Therefore, when this vapour is cooled and condensed, the condensate will contain more volatile and light components. Distillation occurs in a vertical column called distillation column.

2.1.1 Distillation column

There are two types of distillation operation which are batch and continuous distillation. The main difference between these two types are continuous distillation is a process without interruption in which a mixture is separated continuously, while batch distillation is a separation where the distillate fractions are taken out gradually in time during the ongoing process (Liptak,2006).

Figure 2.1 shows the example of the binary continuous distillation column for a single process where stages are in series where the liquids and vapours can flow from one stage flow counter current to each other. The vapour from the stage below flow upwards to the stage above while the liquid flow downwards from the upper stage to the lower stage.

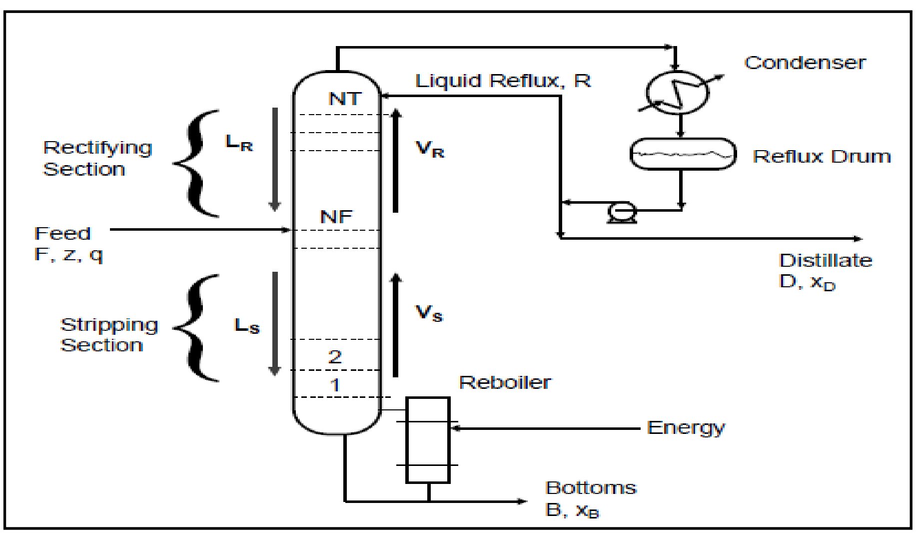

Figure 2.1 N-Tray binary distillation column with reflux
(Source: Luyben, 2006).

2.1.2 Importance of distillation control

Distillation is an important technique to separate substances. Almost 40,000 distillation columns are operated in the U.S (Riggs, 2006). Therefore, controlling the distillation column is a must as it has a big impact towards the quality of product, process production rates energy consume, and cost of the process. According to Kanthasamy in 2009, distillation takes up to more than 50% costs of the operating plant. It is half of the costs.

However, to control a distillation column is not an easy matter. Distillation columns give a very challenging case study in the aspect of process control and dynamics. In 2006, Riggs stated in his study that distillation control is a challenging problem because of the factors such as nonlinearity distillation, multivariable coupling, severity of disturbances and nonstationary behaviour.

2.1.3 Controlling the distillation column

In every process, the choice of control structures for distillation columns is important to get the desired product. Basically, there is no specific structure for all columns, so each column should be controlling differently. In addition, find a structure that will control the columns is crucial. According to Willis in 2008, manipulated variables are adjusted to resist the effect of disturbances and ensure the operation is stabilizing. Material and energy balances will determine the relationships between the input and output.

He also stated that the effective operation of a distillation column is determined by the control of many variables such as composition of the distillate stream, composition of the bottoms stream, liquid level in the reflux drum, liquid level at the base of the column and pressure in the column.

Liptak (2006) added in a binary distillation process, the common variables are the compositions of the bottom and top products, the levels in the column base and accumulator, and the column pressure. The manipulated variables that can be assigned to control these are the distillate, bottoms and reflux flows, the vapor boil-up, and heat removal.

2.2 Proportional- integral–derivative controller (PID)

PID is a combination of all three types of control methods that are proportional, derivative and integral controller. PID-control is most commonly used because it combines the advantages of each type of control. PID controllers are used in a wide variety of industrial control systems and are the most commonly used feedback controllers in the world (Ziff, 2007).

2.2.1 Overview of PID

PID is a generic control loop feedback mechanism that involves three separate parameters: the proportional, the integral and derivative values, denoted P, I, and D.PID comes in three forms which are parallel, series and expanded form. Generally, basic idea of PID control is to compare the set points with the process output as well astuning the three parameters in order to minimize the error (Li, 2010). Basic structure of PID is shown in Figure 2.2.

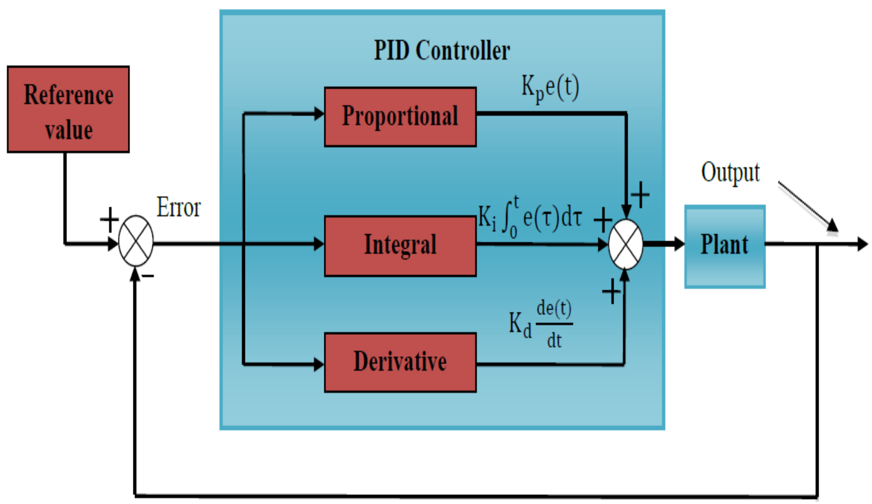

Figure 2.2 Basic structure of PID
(Source: Li, 2010)

As we can see from Figure 2.2, in order to have the output of the system, the error between the values is minimized by PID controller through adjusting the control input. PID-control also correlates the controller output to the error, integral of the error, and derivative of the error. Then, in order to calculate the output of the PID controller, the formula can be expressed below (Scrcek et. al).

$$c(t) = K_c(e(t) + \frac{1}{T_i}\int e(t)\,dt + T_d\frac{de}{dt} + C \qquad (2.1)$$

Where c (t) is controller output, K_c is controller gain, e (t) is error, T_i is integral time, T_d is derivative time constant, and C is initial value of controller

2.2.2 Tuning of PID Control parameters

According to Li in 2010, better performance can be achieved by adjusting the control parameters to satisfy the desired control response or it is called tuning the control loop. For PID controller, the three parameters Kp, Ki and Kd have different effect on system control which is summarized in Table 2.1.

Table 2.1 Effects caused by increasing the PID control parameter individually

PID Control Parameters	Rise Time	Overshoot	Setting time	Steady State error	Stability
Kp	Decrease	Increase	Small change	Decrease	Reduce
Ki	Decrease	Increase	Increase	Large Decrease	Reduce
Kd	Small Decrease	Decrease	Decrease	Small Change	Small change

(Source: Li, 2010)

Typical steps for designing a PID controller are stated by Zhong in his journal (2006). There are four steps which are determine what characteristics of the system needs to be improved, use KP to decrease the rise time, use KD to reduce the overshoot and settling time and use KI to eliminate the steady-state error. Zhong also stated that there is also Ziegler and Nichols carry out several experiments and planned rules for determining values of KP, KI and KD based on the transient step response of a plant.

2.2.3 Disadvantages of PID

Although PID controllers are the most widely used control mechanism, PID has many disadvantages in controlling. For example, PID can only handle columns that are operated by single-input single-output (SISO) controllers and usually used as single-loop controller. This will leads to the waste of useful products and excessive energy. In any cases, PID controllers are very limited in their capabilities, especially when performing a task that are a complex process (Halvorsen, 2011).

2.3 Introduction of Advanced Process Control (APC)

As time pass by, the process control problems have become more and more difficult. In need with that, combinations of advanced hardware and control algorithm have been produce for better controller performance. APC is one type of modern controller. As Robinson and Cima (2006) states in their journal, APC applications